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Operator Performance in Pattern Matching as a Function of Reference Material Structure

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Naval Air Warfare Center Weapons Division

FOREWORD

This report documents research performed at the Naval Air Warfare Center Weapons Division (NAWCWPNS), China Lake, Calif., during fiscal years 1992 and 1993 as part of an investigation of operator performance in multi-sensor targeting. The effort was supported by funds from Human Factors Technology Project (RS 34H20) under the direction of Mr. Jeff Grossman, Naval Command Control Ocean Surveillance Center (NCCOSC), Research, Development, Test, and Evaluation (RDT&E) Division, San Diego, Calif.

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13. ABSTRACT (Maximum 200 words)

    (U) This report describes the results of two experiments that examine operator accuracies and response times to recognize matches and mismatches between line drawings and photographs. The line drawings used in the experiments were generated by the procedures used in the Land-Attack Multi-sensor Correlation (LMC), which is a targeting system under development at China Lake. The experiments varied the number of pixels in the line drawings, the manner in which the pixels were varied, and the kind of pre-mission experience the operators had with the imagery. In addition, the performance results were used to demonstrate an approach that might be used to set a criterion score for calling out a match by the LMC.

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CONTENTS

INTRODUCTION

The goal of a precision strike is to transit to the theater safely and to project lethal force precisely against a sophisticated enemy, all with relatively few casualties and a minimum of collateral damage. The ability to attack safely and precisely in all lighting and weather conditions requires precision aimpoint selection either at stand-off ranges or during single-pass, low level, direct attacks. For stand-off attacks, new targeting concepts are needed in order to utilize imaging sensor information that has never before been available in the cockpit of an attack aircraft. For successful low level attacks, new techniques must be developed that permit the pilot to locate a target and release a weapon in the few seconds available in a single, high speed pass.

The Land-Attack Multi-sensor Correlation (LMC) project under development at the Naval Air Warfare Center Weapons Division (NAWCWPNS), China Lake, Calif., is designed for either stand-off or direct attack. It will locate offset aim points or targets by correlating incoming sensor imagery in a cockpit with reference materials derived from three-dimensional models of the target or aim point area stored on board the attack aircraft. These three-dimensional models are created prior to the mission from various sources (including satellite imagery, aerial surveillance photographs, and digital maps). During the mission, the position (azimuth and elevation) and orientation of the aircraft sensor are used in conjunction with the model to generate a line drawing of the target area in the proper perspective. In the cockpit during the mission, the LMC correlates these line drawings with edge enhanced sensor imagery and notifies the pilot when a peak correlation is found. The pilot need only glance at an overlay of the line drawing and sensor imagery to verify the match and initiate weapon release. The correlation and the pilot verification process can both be accomplished in only a few seconds.

An experiment conducted in 1992 determined that it took an average of 2.5 to 5 seconds for an operator to determine if there was a match between a line drawing and a photograph of a scene (Reference 1). Various response times (RTs) in this range were associated with whether the line drawing was overlaid or shown beside the photograph; whether it was accurately overlaid, rotated, or offset from the photograph; whether the color of the line drawing was green or white; and whether the line drawing matched the photograph. Most importantly, the experiment showed that the entire range of RTs of an operator using the LMC was less than the 8 to 10 seconds typically available for targeting in a low level attack mission.

The experiment lacked generality in two ways: (1) The line drawings were generated in a manner that modeled the procedures of the LMC, but did not result in drawings that looked like the LMC drawings. The experiment's drawings appeared more complete, with longer and more connected lines than the drawings generated by the LMC algorithms. (2) The line drawings in the experiment contained many more pixels than the drawings used in real time by the LMC correlator. New developments had shown that the number of pixels that the correlator could handle in real time was somewhere between 1500 and 2500; many of the line drawings in the experiment exceeded 10,000 pixels.

Intuitively, some templates and images are probably easier to match than others; also intuitively, a large reduction in the number of pixels that constitute a line drawing should make pattern matching more difficult. However a search of the literature did not provide consistent or relevant information on the accuracy and speed of pattern matching of this type. Most of the experiments that are reported do not deal with pattern matching but rather with pattern recognition (the ability to assess with accuracy if one has or has not previously seen a given pattern) or with pattern recall (the subsequent ability to provide an accurate description of a pattern that one has seen earlier, without being provided with an example). Thus application of the experimental results to pattern matching is not necessarily straightforward. In addition, the results from experiment to experiment often conflicted, and different specific measures for recall and recognition were used from report to report.

For example, Ryan and Schwartz found that line drawings of objects were the most difficult to perceive accurately, and that cartoons were the easiest, with photographs and shaded drawings about equal to each other and falling between the other two (Reference 2). The perception measure taken in this experiment was exposure time of the image until an accurate pattern matching response was produced by the observer. Pattern matching in this case involved manipulating an object (such as a set of switches) so that the object appeared in the same configuration and aspect as the objects in the pictures. There was a substantial interaction between the object being portrayed and the optimum method of portrayal, so that for some objects, line drawings led to the worst pattern matching, but for others, line drawings worked very well.

In contrast, Nelson, Metzler, and Reed found that there were no differences between photographs, unembellished line drawings (drawings without details), and embellished line drawings (with added details) for either immediate or delayed recognition (Reference 3). Recognition was measured as the percent of trials in which the subjects correctly chose the images that they had previously seen in two alternative forced choice tests. All three were significantly better than verbal descriptions for recognition of the images.

A final example by Loftus and Bell (using Nelson's photographs and line drawings) showed that the photographs were more frequently recognized in forced choice tasks than were line drawings (Reference 4). Further, all imagery in which a detail was recalled was recognized more readily than imagery with no recall of details. Loftus and Bell believe that recognition of imagery may be based either on specific detail information or on general visual information. The latter process accrues information gradually over time, explaining the common finding that the longer an image is viewed, the more information is accrued. The authors theorize that while accruing information, the observer is simultaneously engaged in a search for a potentially informative detail. If such a detail is located, recognizability of that image makes a quantum jump. The potential of finding a significant detail, they believe, is greater in a photograph than in a line drawing, even if the line drawing is embellished.

Historically, recognition of imagery has been believed to be based upon two types of information: a verbal component (many experiments have shown that verbal descriptions of a scene being viewed improves subsequent recognition), and a nonverbal or visual component (scene recognition still occurs when verbalization is

prevented). The authors propose that the finding of a significant detail acts much the same way that verbalizations aid in image recognition. That is, what they " . . . have termed specific detail information is equivalent to what others have described as the verbal component of picture memory . . . " (Reference 4, page 112).

The findings reported in the literature and summarized above. and their interpretations, may also apply to the pattern matching required of the operator who verifies the output of the LMC. While the experiments do not provide consistent results, the literature suggests that recognition of objects is possible. if not optimum, from line drawings of the objects. Presumably also, line drawings can be used for pattern matching. Similarly, if recognition is based both on visual information and on a verbal/detail component, pattern matching is also probably based upon similar components. Therefore pattern matching will probably be facilitated by images and templates that provide not only general visual information but also details that can be matched. If that is the case, the fewer the pixels in a line drawing, the less likely it is that a detail will be included, and the more difficult it should be to verify a match. By similar reasoning, verbal descriptions of scenes and target areas should also facilitate pattern matching.

This report describes the results of two experiments that re-examine operators' accuracies and RTs to recognize matches and mismatches between line drawings and photographs. The line drawings used in the experiments were generated by the procedures used in the LMC. The experiments varied the number of pixels in the line drawings, the manner in which the pixels were varied, and the kind of pre-mission experience the operators had with the imagery. In addition, the performance results were used to demonstrate an approach that might be used to set a criterion score for calling out a match by the LMC correlator.

METHOD

Two experiments were designed together and share the same materials. Seventy-two photographs of a variety of scenes were digitized for computer processing. Each of the images was processed using the LMC algorithms so that after processing. edges of sufficient contrast, continuity, and length in the original picture were represented by lines. The lines for each picture were made of approximately 5000 pixels; these constituted the basic line drawings from which the stimuli for both experiments were derived.

EXPERIMENT 1

Stimuli

For each of the 72 photographs in the first experiment, 12 line drawings were created. Each of the 12 line drawings represented a variation of level in two basic factors: Pixel Count, which varied by having either 1000, 2000, 3000, or 4000 pixels in a drawing; and by Reduction Method, which was used to reduce the basic line drawings from 5000 pixels to the required pixel count. In this experiment all

Reduction Methods were computerized processes. There were three Reduction Method levels:

1. The Long Reduction Method ("Long"), in which the computer successively removed the shortest line from the basic drawing until the appropriate total number of pixels remained. Thus the final line drawings in "Long" condition were made up of the longest lines from the basic drawing; there were four pixel count levels in the Long condition, which contained either 1000, 2000, 3000, or 4000 pixels (see Figure 1).

2. The Center Reduction Method ("Center"), in which the computer successively removed lines, starting with the farthest away from the physical center of the basic drawing, until the appropriate number of pixels remained. Thus the final "Center" drawings were composed primarily of lines in the physical center of the drawing and contained 1000, 2000, 3000, or 4000 pixels.

3. The Random Reduction Method ("Random"), in which the computer successively removed random lines from the basic line drawing until 1000, 2000, 3000, or 4000 pixels remained. This was essentially a control condition. Figures 1 and 2 shows examples of the three Reduction Methods.

(a) "Oil tanks on the hills by the shore."

FIGURE 1. An Example of One of the 72 Photographs Used in the Experiment, and the Line Drawings With 1000, 2000, 3000, and 4000 Pixels Generated For It by the LMC Using the "Long" Reduction Method.

(b) Basic line drawing used in both experiments: 5000 pixels.

(c) 1000 pixels.

(d) 2000 pixels.

(e) 3000 pixels.

(f) 4000 pixels.

FIGURE 1. (Contd.)

(a) Long Reduction Method: 2000 pixels.

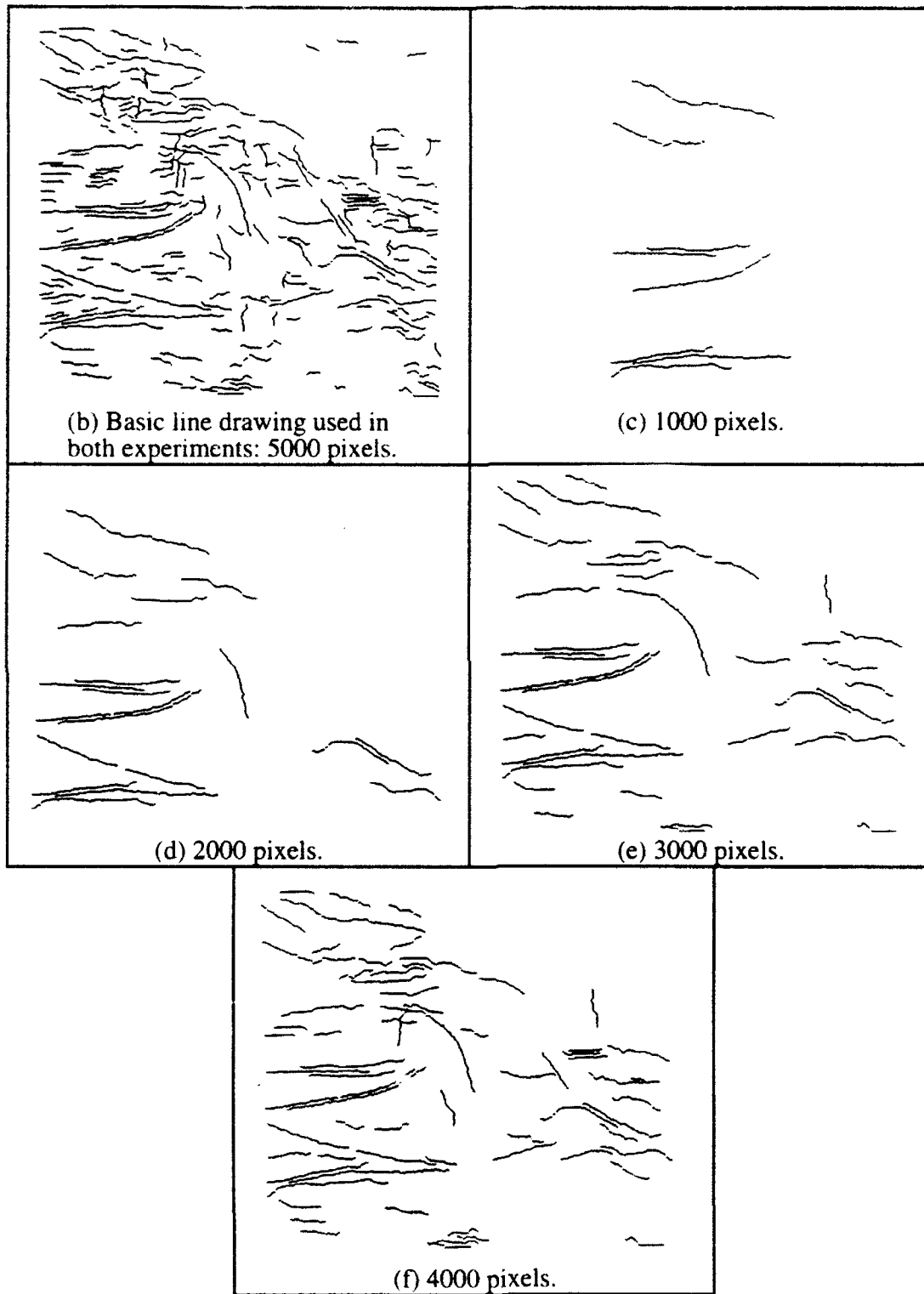(b) Focus Reduction Method: 2000 pixels.
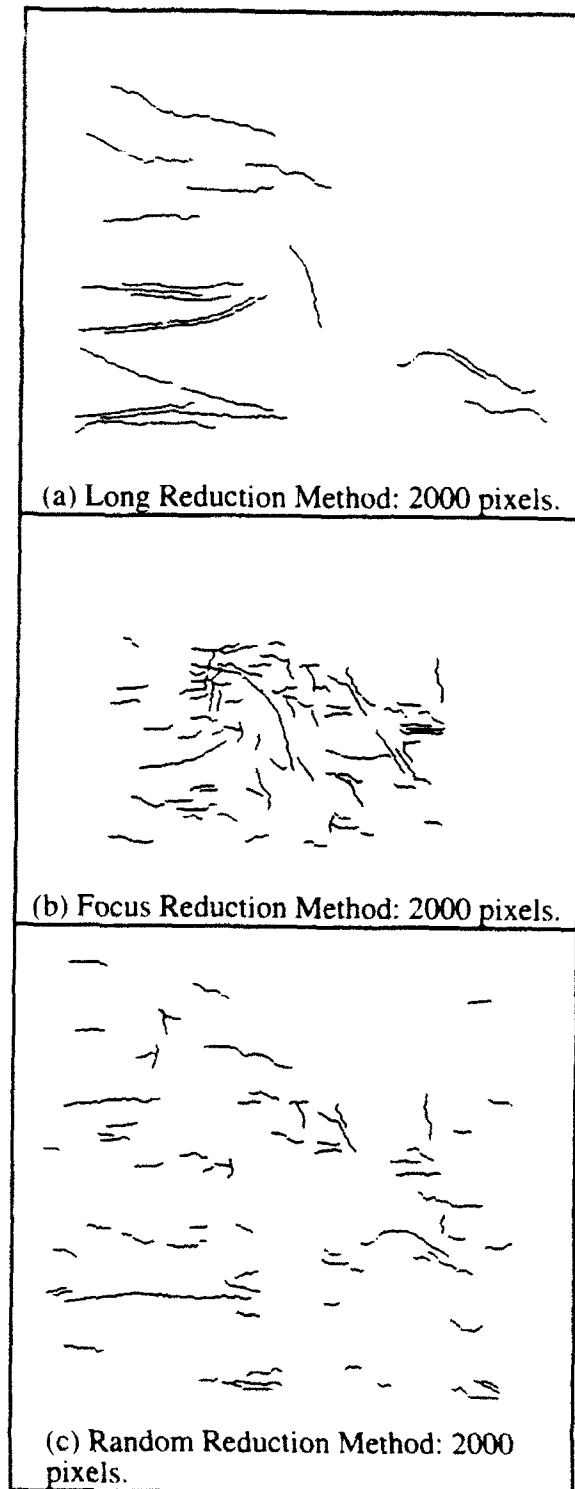
(c) Random Reduction Method: 2000 pixels.

FIGURE 2. Oil Tank Farm Line Drawings Resulting From the Three Reduction Methods.

Matches and Mismatches

To create the matching condition, the appropriate line drawing was superimposed over the picture from which the drawing was originally created. Mismatches were created by superimposing a line drawing over an image from which it was not created. For mismatches, the placement of the incorrect drawing was done with care, to make the "best matched" mismatch, that is to have the drawing lines correspond as closely as possible to the edges in the photograph.

Equipment

The photographs and overlaid line drawings were recorded using a Panasonic TQ-2023 Optical Disk Recorder. The imagery was stabilized during the recoding with a JVC KM-F250 Frame Synchronizer. During playback both the Panasonic Recorder and a Panasonic TQ-2027 Optical Disk Player were used to present the imagery on a Sony PVM-1910 Trinitron monitor. The experiment was controlled and the results recorded by a Foundation 80386 Computer.

Subjects

Experiment 1 used 16 subjects who were male or female civilian employees of NAWCWPNS, China Lake. No individual subject participated in more than one test connected with any part of these experiments.

PROCEDURE

Experimental Design

Experiment 1 used a factorial design with three fully crossed factors. The factors were: (1) Pixel Count (1000, 2000, 3000, 4000); (2) Reduction Method (Long, Center, and Random); and (3) Matching (Matched and Mismatched).

Randomization Procedure

Prior to recording any imagery on the laser disc, a set of image–line drawing pairs was established for each person. For matches, each subject had the same set: a line drawing superimposed over the photograph from which it was created. For mismatches, each subject saw the same 72 photographs, but each was paired with a mismatched overlay created from one of the 71 other photographs. The base photograph for a mismatch line drawing was preselected randomly, without replacement, from the pool of possible mismatches. Thus there were 72 matching pairs and 72 mismatching ones, for a total of 144 images.

Next, a matrix was built that, for each of 16 subjects, assigned the 72 matches and 72 mismatches to each experimental condition. The design of the experiment called for 6 replications of the 12 conditions (3 Reduction Method conditions x 4 pixel count conditions) for matches and for 6 replications of the 12 for mismatches. Thus altogether there were 72 matching trials and 72 mismatching trials. For each subject separately, the 72 matched and 72 mismatched pairs described above were

randomly assigned, without replacement, to these 72 matching and mismatching trials.

Test Procedure

Subjects were told the general nature of the experiment and shown the equipment used in the test. Then the computer provided instructions for subjects on what they would see, provided three examples of matches and mismatches, and instructed them on how they should respond. In each trial the subject was to determine as rapidly as possible whether the line drawing matched or mismatched the photograph. Each subject was then shown, in random order, the 144 images that had previously been recorded. Responses and RTs were recorded for each trial. The entire test took from 15 and 30 minutes for each subject.

RESULTS

Percentage of Correct Responses

The mean percentage of correct responses for the three Reduction Methods, the four levels of pixel counts, and the two matching conditions are listed in Table 1.

TABLE 1. Percentage of Correct Responses in Experiment 1.

	Correct response, %	Response time, sec
Reduction Method		
Random	85.4	3.25
Center	82.1	3.21
Long	92.5	2.75
Pixel limit		
1000	82.5	3.2
2000	86.3	3.18
3000	89.1	2.96
4000	88.7	2.95
Matching		
Matched	86.7	3.14
Mismatched	87.5	3.01

These findings were analyzed using a repeated measures Analysis of Variance (ANCVA). The main effect for Reduction Method was significant [F (2, 28)= 17.22, P< 0.001], as was the main effect for Pixel Count [F (3, 42)= 5.41, P< 0.003]. There were no significant differences in percent correct between matches and mismatches, with matches recognized correctly 86.7% of the time, and mismatches recognized correctly 87.5% of the time. The 2 two-way interactions that involved matching were both significant, with Matching x Reduction Method significant at the 0.004 level [F (2.28) = 6.71] and Matching x Pixel Count significant at less than the 0.001 level [F(3, 42) = 8.20]. These relationships are shown in Figures 3 and 4.
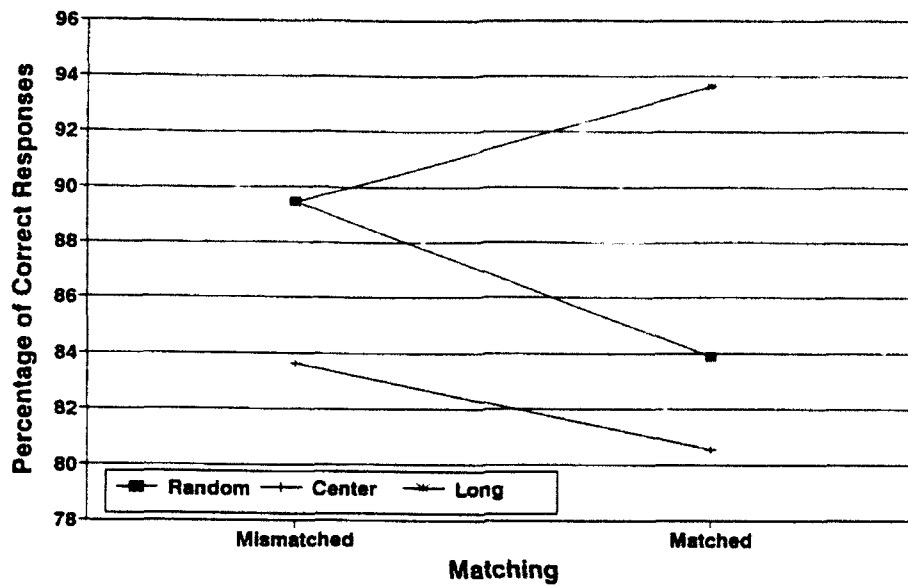
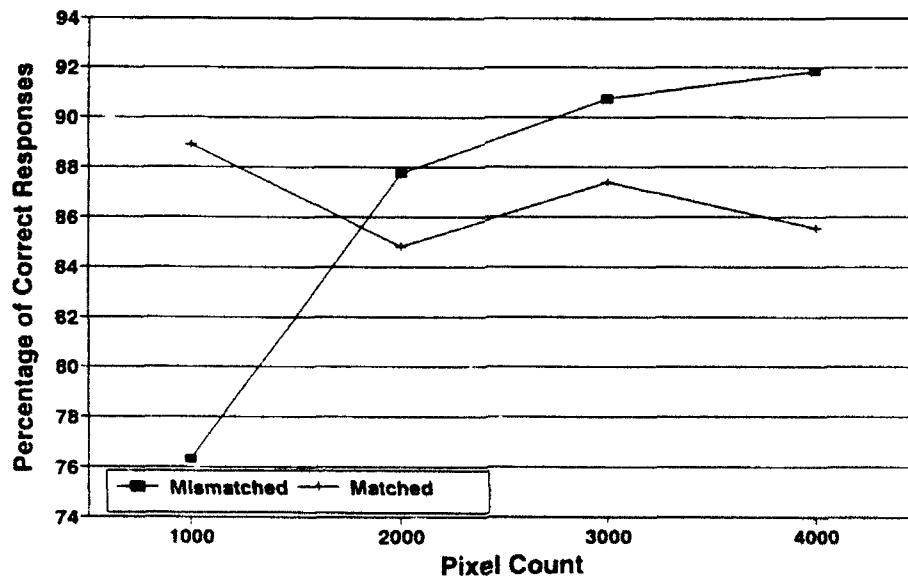FIGURE 3. Percentage of Correct Responses for Reduction x Matching Interaction.

FIGURE 4. Percentage of Correct Responses for Matching x Pixel Count Interaction.

Contrasts for the Reduction x Matching Interaction show that for percent correct, Long in the matching condition was significantly higher than for all of the other five conditions [F(1,14)= 7.3, P< 0.02], and that the other five conditions did not vary from one another. Analysis of the Pixel Count x Matching interaction show that the percentage of correct responses increased significantly with increases in pixel count in the mismatches [F(2,177)= 13.924, P<0.001], but not in the matches. Both linear and quadratic components were significant for the mismatches, indicating the presence of an upper boundary in percent correct somewhere between 3000 and 4000 pixels.

The two way interaction between Reduction Method and Pixel Count was marginally significant [F(6, 84)= 1.15, P<0.07]; the general tendency was for the differences in percentage of correct responses for each Reduction Method became smaller as the number of pixels in the line drawing increased. This relationship is shown in Figure 5. There were no other significant findings in the analysis; the three way interaction was not significant.
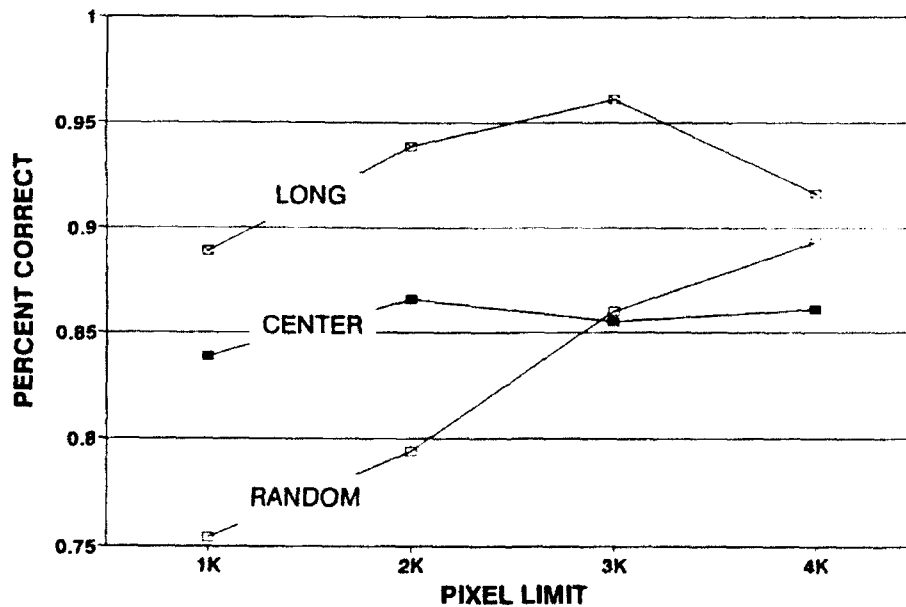
FIGURE 5. Percentage of Correct Responses for Reduction x Pixel Count Interaction.

Response Time

The ANOVA for RT used the mean RTs for correct responses only (see Table 1). The only significant main effect in the analysis was for Reduction Method; contrasts showed that the Long Reduction Method led to significantly faster responses than both the Center and Random methods. Center and Random Reduction Methods did not differ from each other in RT.

There was a significant interaction between Matching and Reduction Method [F(2.28) = 12.33, P < 0.001] and a marginally significant interaction between Matching and Pixel Count [F(3,42) = 2.58, P < 0.07]. These interactions are shown in Figures 6 and 7. Contrasts analyzing the Matching x Reduction Method interaction show that the Long for matches had a significantly faster RT than the other five conditions [F(1,14)= 13.27, P < 0.003]. In the Matching x Pixel Count interaction, most of the variation in RT seems to be a reduction in RT as pixel count increases in the mismatches, but there was little variation in RT to recognize matches.
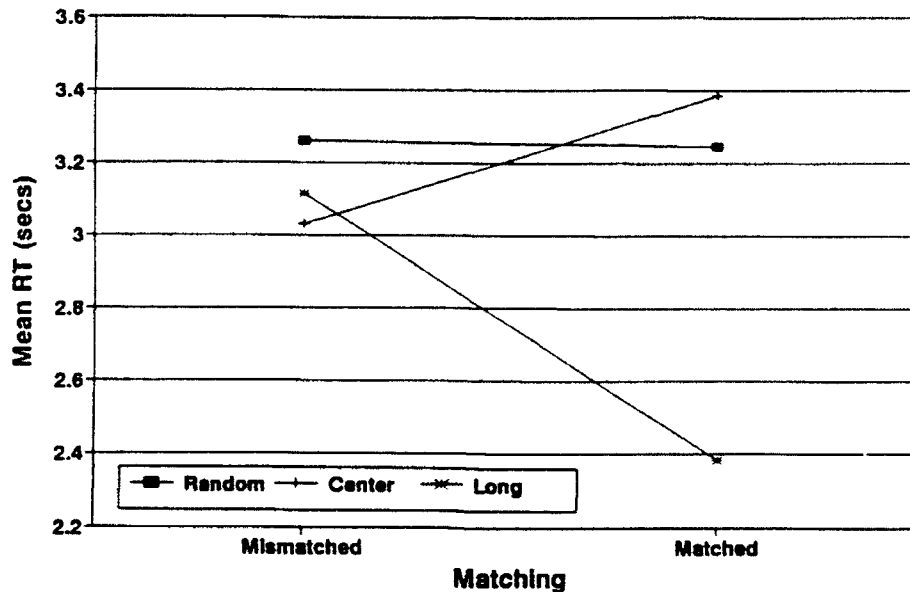
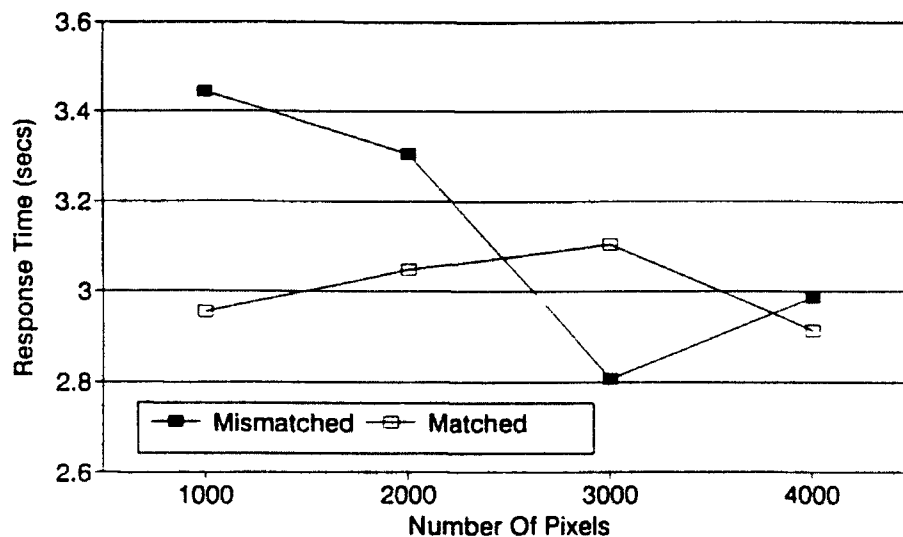FIGURE 6. Response Times for Matching x Reduction Method Interaction.

FIGURE 7. Response Times for Pixel x Matching Interaction.

DISCUSSION

Overall, the Long line drawings were superior in both accuracy and speed to the drawings produced by the other Reduction Methods. The advantages of the Long line drawings were apparent primarily in the matching conditions, where operators using them could verify matches approximately 1 second faster and with greater than 10% higher accuracy than they could using line drawings made with the Focus or Random Reduction Methods (see Figure 2). In the final phases of a low level attack, 1 second saved translates into approximately 1/8 mile, and represents a large proportion of the 8 to 10 seconds available for targeting.

The findings for Pixel Count showed that in general, operators perform faster and more accurately when there are more pixels in a line drawing. The increases in performance accuracy, however, level off between 3000 and 3500 pixels, and beyond that, there is no further performance gain. Further, the effect of pixel count shows primarily in the operators' ability to recognize mismatches, which in the real LMC operation, would equate to the operators' ability to correct false alarms that may be called out by the correlator. The pixel count had far less effect on the operators' ability to verify matches.

The design implications from Experiment 1 are clear:

1. Make templates that consist of fewer, longer lines
2. If the final implementation of the LMC produces a large number of false alarms that need to be corrected by an operator, then increase the number of pixels in the line drawings to 3500 in order to increase the ability to recognize the false alarms.

These two steps should maximize the contribution of the operator in system performance of the LMC.

EXPERIMENT 2

INTRODUCTION

While the first experiment demonstrated that Long line drawings produced superior pattern matching performance, it is clear that some of the lines used in these drawings are surprising and would not have been included if the drawings had been made by hand instead of by computer. While all of the lines in the drawings corresponded to an edge in the photograph from which it was made, many edges were omitted that were more important from a conceptual point of view, but which had less contrast. We could not help wondering whether operator verification of pattern matches of the sort required by the LMC might be fastest and most accurate if the line drawing used for matching represented the scene in a way more cognitively compatible with operators' expectations. We examined this possibility in Experiment 2.

The first experiment failed to show any advantages for the Center line drawings. That result was somewhat surprising because the Center method of reduction seemed

to emphasize the central area of a scene, which would be likely to contain the greatest amount or the most important information. However, further examination of this idea led to the thought that the area of greatest importance in a scene might not be in the physical center of the picture, but might well be in some other, off-center area. So in Experiment 2 we reexamined this method of reduction so that the line drawings would focus on an area of high information content for each picture, wherever it may be in the picture.

Finally in Experiment 2, we wanted to see if the operator's participation in making a line drawing or in careful study of a scene would enhance his subsequent performance in verifying the output of the LMC. Would pilots benefit from making their own line drawings in mission planning, or would they add accuracy and speed in using the LMC by adding verbal commentary to imagery obtained in the planning process?

METHOD

Stimuli

The line drawings in the second experiment were varied only by the Reduction Method, which had four levels:

1. The Concept Reduction Method ("Concept"), which, unlike the methods of Experiment 1, was done manually. First, brief two-line written descriptions of each of the 72 images were given by four volunteers. These descriptions were collated and from them, descriptions were generated that represented a consensus description. The basic line drawings were then manually reduced so that only lines contained in the consensus descriptions remained. For example, the consensus description of photograph number one (see Figure 1) was "Oil tanks on the hills by the shore." Only lines representing hills, shore, or oil tanks were left in the line drawings. Lines representing roads, buildings, or docks were removed. (Figure 8 provides examples of the line drawings constructed by the Reduction Methods in Experiment 2.)

2. The Focus Method ("Focus") was similar to the Center Reduction Method described for Experiment 1, except that lines were successively removed that were the furthest away from a focal point of interest in the photograph (rather than from the physical center). The focal point of interest for each picture was determined manually following a procedure outlined by Mackworth and Morandi, who showed that their manner of eliciting subjective judgments of picture areas of importance correlated positively with the total number of visual fixations on those areas (Reference 5). Focal points were determined by having seven judges place a circle around what they each thought was the focal point of the picture. The focal point for each picture was determined to be the one chosen by the largest number of judges, and lines furthest from this point were successively removed.

3. The Long Reduction Method ("Long"), which was described in the "Stimuli" section of Experiment 1.

4. The Random Reduction Method ("Random"), which was described in the "Stimuli" section of Experiment 1.

The pixel count of the four line drawings made for each photograph in Experiment 2 was held constant by matching each one to the pixel count of the line drawing generated by the Concept Reduction Method. The pixel counts for the Concept drawings were kept within the limits imposed by the requirements for real time correlation by the LMC; the counts ranged from 712 to 2668 pixels in the 72 drawings. In the four line drawings produced for each photograph, the pixel count did not vary more than 60 pixels. (The Appendix to this report lists the verbal descriptions of each photograph and the pixel count for the Concept Reduction Method.)

(a) Picture 1 concept; Reduction Method: 1500 pixels.

(b) Picture 1; Long Reduction Method: 1496 pixels.

(c) Experiment 2: Focus Reduction Method: 1500 pixels.

(d) Experiment 2, picture 1; Random Reduction Method: 1496 pixels.

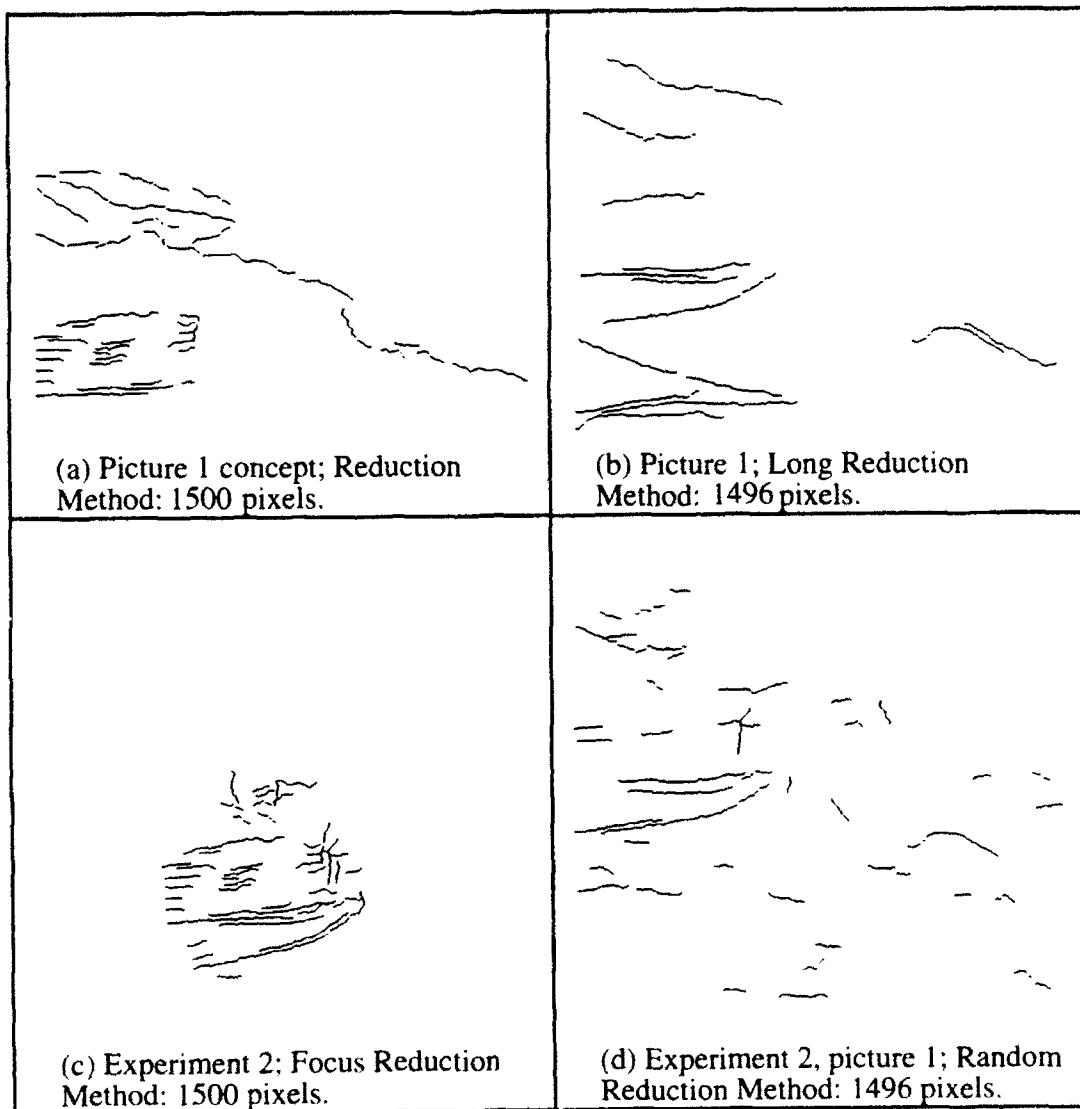FIGURE 8. The Oil Tank Farm Line Drawings Generated by the Reduction Methods Used in Experiment 2.

Preview Conditions

In Experiment 2, subjects were given three different pretrial exposures with the photographs. In the Verbal Condition, subjects were given 20 seconds to write short descriptions of one third of the photographs that were presented in hard copy. In the Image Condition, subjects were given hard copy photographs of a second third of the scenes, each covered by a transparency. They were given 20 seconds to trace significant features of each photograph onto a transparency, creating their own line drawing of each photograph. For the final third of the photographs, subjects had no pretrial experience.

Matches and Mismatches

Matches and mismatches were created in this experiment in the same way that they were created in Experiment 1.

Equipment

The equipment used in Experiment 1 was used in this experiment also.

Subjects

As in the first experiment, 16 China Lake employees were used in this experiment. Subjects for Experiment 2 had not participated in the first experiment, pretesting, or as a volunteer in describing scenes or locating focal points for this experiment.

PROCEDURE

Experimental Design

In Experiment 2 the independent variables in the factorial design were: (1) Preview Condition with three levels (None, Verbal, and Image); (2) Reduction Method with four levels (Concept, Long, Focus, and Random); and (3) Matching with two levels (Matched and Mismatched). With six replications for each condition, there were 144 trials (72 matching and 72 mismatching).

Randomization Procedure

The procedure described for Experiment 1 was used to make 72 matching and 72 mismatching pairs. In addition, a similar procedure was used to assign the pairs to the experimental conditions, except that to save time and reduce the number of recordings that had to be made, the matrix was made for only eight subjects, and the assignments were repeated for the second group of eight subjects that were to participate in the experiment. As in the earlier experiment, the 72 matching pairs were randomly assigned without replacement to the 72 matching trials, and the 72 mismatching pairs were similarly assigned to the 72 mismatching trials. Once these assignments were made for each of the eight subjects, the appropriate images were constructed and recorded.

Test Procedure

The test procedure for Experiment 2 was similar to that for Experiment 1, except that prior to the events outlined above, each subject first drew line drawings for 24 photographs and then wrote descriptions of 24 other photographs. The entire test for each subject took approximately 90 minutes.

RESULTS

Percentage of Correct Responses

Table 2 lists the percentage of correct responses for each of the three factors in this experiment: Reduction Method, Matching Condition, and Preview.

TABLE 2. Percentage of Correct Responses in Experiment 2.

	Correct response, %	Response time, sec
Reduction Method		
Concept	93.9	4.07
Long	94.4	4.33
Focus	83.7	4.94
Random	85.3	5.17
Preview		
None	88.7	4.72
Template	90.0	4.45
Verbal	89.3	4.73
Matching		
Matched	88.6	4.90
Mismatched	90.1	4.36

A within subjects ANOVA on these data showed that there was a significant main effect for Reduction Method [$F (3,51)=18.30$, $P<0.001$]. Contrasts show that the percentage of correct responses for the Focus and Random methods considered together was significantly less than for the Concept and Long methods taken together [$F (1,17)= 42.95$ $P< 0.001$], but that there is no difference in percentage of correct responses between the Focus and Random technique or between the Long and Concept technique. No other main effect was significant.

There was only one significant interaction, Matching x Reduction Method [$F(3, 51)= P<0.001$]. This relationship is shown in Figure 9. Contrasts demonstrate that there are no differences in percentages of correct responses in the mismatches due to Reduction Method, but there are significant differences in the matches. The Focus and Random methods taken as a pair led to significantly less accurate responses than the Concept and Long paired together [$F(1, 17)= 95.78$, $P < 0.001$]. However there were no differences between the members of each pair taken separately.
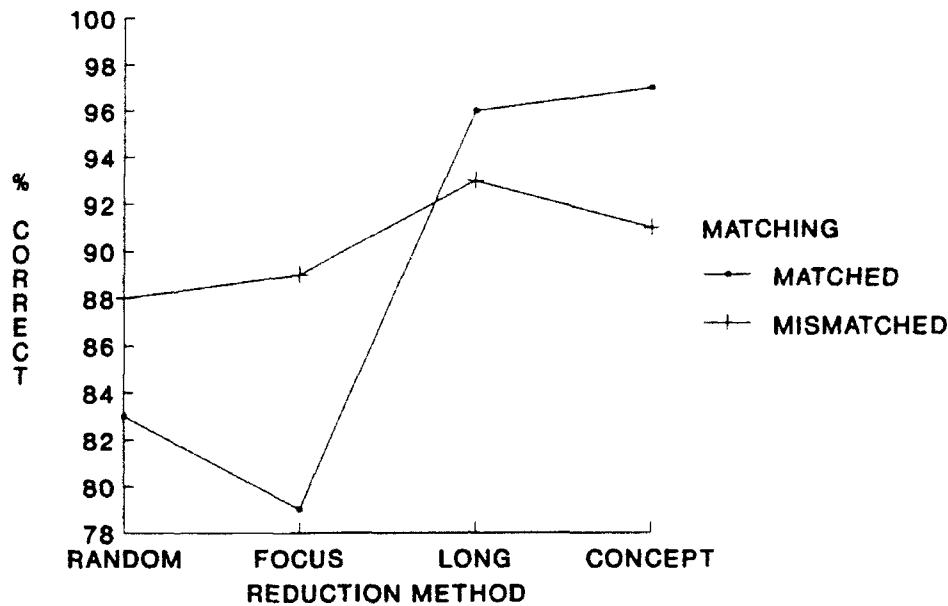
FIGURE 9. Percentage of Correct Responses for Matching x Reduction
Method Interaction.

Response Time

Times for correct responses for each of the three factors in Experiment 2 are
shown in Table 2. There was only one significant main effect in the repeated
measures ANOVA used to analyze these data, Reduction Method [$F(3,48) = 8.75$, $P<$
0.001]. Contrasts showed that the Concept and Long Reduction Methods led to faster
RTs than the Focus and Random methods [$F(1,16)= 16.69$, $p<0.009$]. Further,
contrasts also showed that there were no differences in RT between the Concept and
Long methods.

Match x Reduction Method was also significant [$F(3,48)= 7.59$, $P< 0.001$], and
Match x Preview was marginally significant [$F(2.32)= 3.17$,$P<0.06$] (see Figure 10).
As before, contrasts showed that the differences in Reduction Methods showed only
in the matching conditions and not in the mismatching conditions, and that the
Concept and Long methods led to significantly faster RTs than the Focus and
Random methods [$F(1,16)= 18.56$, $P<0.001$]. Contrasts to assess the significance of
the Preview x Match interaction showed that there was a significant difference that
showed only in the matched condition, such that pretraining in making line drawings
led to significantly faster RTs than either of the other two pretesting conditions (no
preview or verbal descriptions), $F(1, 16) = 6.76$ and 7.46, respectively, $P <0.02$ and
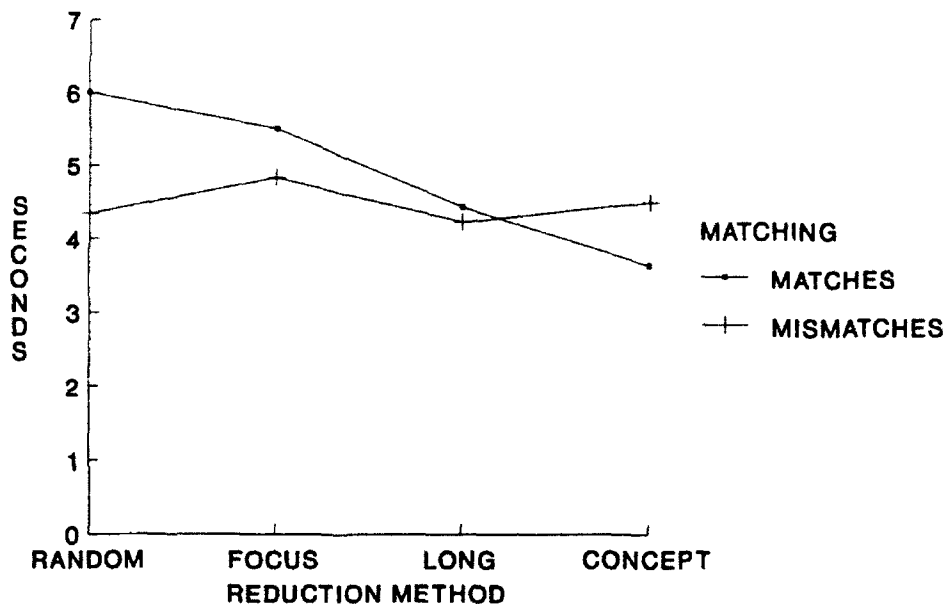<0.01].

FIGURE 10. Response Times for Matching x Reduction Method Interaction.

Finally, the three way interaction of Match x Preview Condition x Reduction Method was significant [$F_{(6,96)}=2.37$, $P<0.04$]. This interaction is shown in Figure 11.
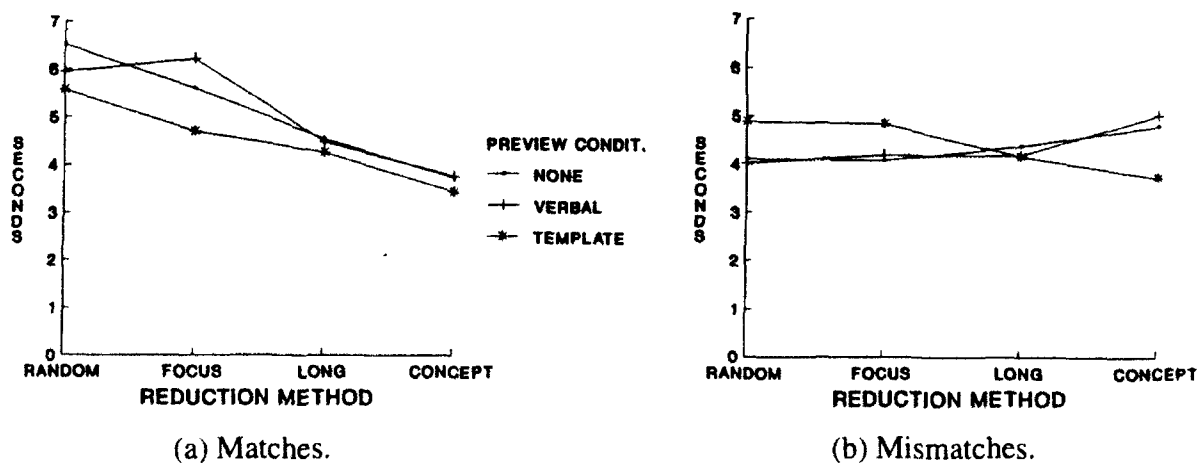

(a) Matches.

(b) Mismatches.

FIGURE 11. Response Times for Three-Way Interaction.

DISCUSSION

This experiment demonstrates that pattern matching using the Long and Concept line drawings was both more accurate and faster than pattern matching with the other types of line drawings. The magnitude of the improvement between the best and the worst was similar to that found in Experiment 1: a savings of approximately 1 second and an improvement of about 11% in accuracy. There was no consistent difference demonstrated between the Long and the Concept line drawings. Because the Long Reduction Method can be completely automated, it is a more desirable method of constructing line drawings for the LMC than the manually based Concept line drawing.

The RTs for this experiment were 1 to 2 seconds longer than the times in Experiment 1. In both, however, the times were well within the time available for targeting in a high speed, low level pass. There is no obvious explanation for the time differences in the two experiments: two different experimenters conducted the testing, which may have inadvertently influenced the time pressure that the subjects perceived; in addition, in Experiment 2 the pretesting experience of drawing templates and describing photographs may have caused the subjects in that experiment to be slower and more thoughtful. Overall operator accuracy in Experiment 2 was 3% higher than in Experiment 1.

Finally, in this experiment as in the first experiment, the gains produced by using the Long and Concept line drawings for pattern matching showed mainly in the accuracy and RTs for verification of matches. Recognition of false alarms (mismatches) did not improve as a function of the type of line drawing. Figure 12 shows the speed and accuracy differences as a function of Reduction Method.
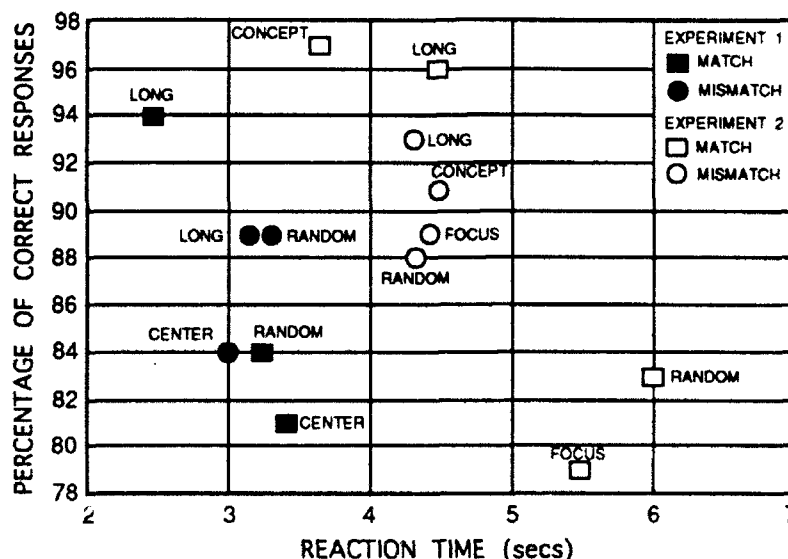
FIGURE 12. Speed and Accuracy Differences as a Function of Reduction Method.

There was some slight evidence that experience in making line drawings speeded up RTs for pattern recognition. Manual tracing of the photographs to make a line drawing of the scene stressed the visual, as opposed to the verbal, aspects of the pattern matching process. Atwood has suggested that pattern matching is primarily a visual task, and that verbalization concerning the patterns to be matched is in effect a encoding of a visual process into a verbal-auditory process and will thus take time and increase RTs (Reference 6). Our findings support this interpretation. However in the pretraining that was used in this experiment, no steps were taken to prevent subjects from verbalizing about the photographs while simultaneously tracing them. Thus our findings do not constitute unequivocal support for this interpretation.

Error analyses showed that errors were greater for some of the 72 images than for others. There was no readily apparent interpretation for these differences. Neither the type of scenery nor the photographic image quality appeared to account for the errors.

Finally, the traced images produced in the pretraining were qualitatively analyzed. There was remarkable consistency between subjects in the lines that were included in the tracings, such that a substantial number of the lines were included by all subjects. In addition, each subject usually included at least one line that was unique. In general, the practice drawings, when digitized, included more pixels than those used in the experiments, and subjectively at least, they appeared to make more coherent, better organized scene representations than the Long or Concept line drawings used in Experiment 2. Intuitively these drawings could be more accurately used for scene recognition than the drawings made by the LMC, which were used so successfully for pattern matching.

CORRELATOR MATCH CRITERION

In the LMC, line drawings will be correlated to edge-enhanced sensor imagery. The correlation that is computed is the sum of the gray scale value of the pixels in the edge-enhanced sensor scene that lie under the lines of the superimposed line drawing. As the view seen from the aircraft sensor approaches that generated from the model (such that the range and viewing angle are the same as the one used to generate the line drawing from the model), the correlation value should increase. This section addresses the question: What should the magnitude of the correlation be for the LMC to call out a match between the line drawing and the sensor imagery?

Our general strategy to address this question was to calculate the correlations between each of our 72 pictures and their matching line drawings (using the Long drawings from Experiment 2), and between each picture and several mismatched line drawings. But because our pictures were of several different sizes and had different levels of contrast from one another, and because each of our templates contained different numbers of pixels, we normalized each one with respect to gray scale, picture size, and template size, before calculation of the correlations. We then plotted the distribution of correlations for both the matches and the mismatches. Figure 13 shows the cumulative percentages of the matches and the cumulative percentages of the mismatches. If a correlation score of 37 was set as a criterion for the LMC, such

that at or above 37 the LMC would call out a match, then from Figure 13 we can see that the LMC would have named about 5% of mismatches as matches (false alarms), and would have omitted calling out about 7% of the real matches (incorrect rejections). In terms of actual frequencies for our sample, with a criterion of 37, the LMC would have had 3 false alarms and 65 correct recognitions (hits). The LMC would have had 5 misses (incorrect rejections) and 61 correct rejections. In the actual system, operators could correct the false alarms, but the way the LMC is currently envisioned, the operators would presumably not see or correct the LMC misses.
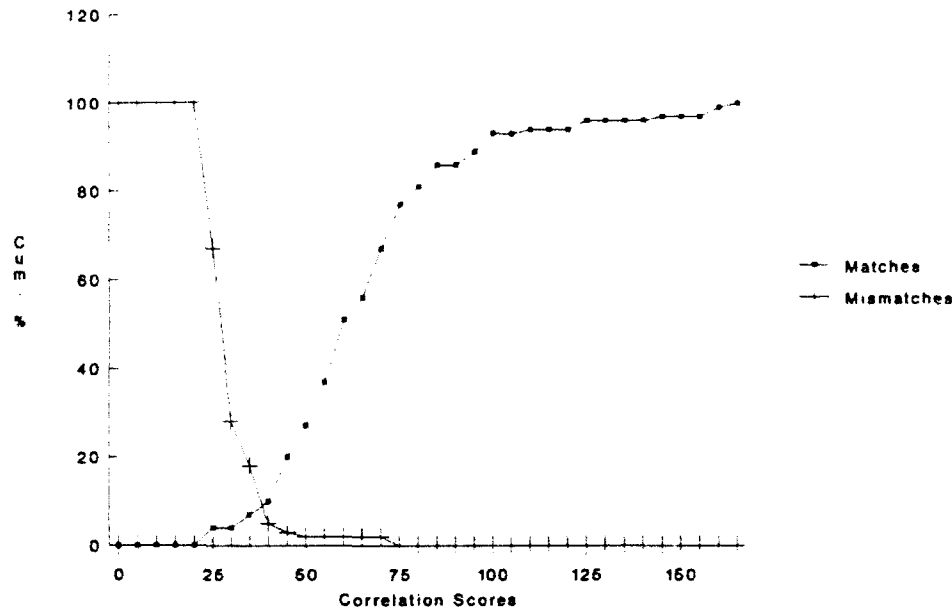

FIGURE 13. Cumulative Frequency Distribution of the Matches and the Inverse of the Cumulative Frequency Distribution of the Mismatches.

In an actual system, the criterion could be adjusted to control either the false alarm rate, the hit rate, or the total error rate. In this example the total error rate was about 12% (5% false alarms and 7% misses); however if it was necessary to control the miss rate to less than 5%, the criterion could be set at 25. The false alarm rate, however, would be expected to rise to about 40%, for an overall error rate of 45%. This example illustrates the trade-offs that the system designers will need to consider when selecting the correlation score to be used as a criterion.

We recommend a similar approach to set the actual correlation criterion for the LMC. To establish a suitable criterion and obtain estimates of false alarms and misses, additional testing will need to occur, using a variety of scenes from actual sensor imagery, along with line drawings that are made from appropriate source materials. By obtaining performance measurements of operators using the LMC, system level estimations of hits, correct rejections, false alarms, and misses can be made. Adjustments of the criterion correlation scores can be used to change these system level parameters, or if acceptable performance levels cannot be reached by adjusting the criterion, then one can alter the number of pixels in the line drawings to improve the operators' ability to recognize false alarms.

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Appendix

**VERBAL DESCRIPTIONS OF EACH PHOTOGRAPH AND PIXEL COUNT
FOR THE
CONCEPT REDUCTION METHOD**

Verbal Descriptions of Four Judges, and pixel counts.

1. Oil tanks on hills by shore. 1500
2. Coastline and bay. 712
3. End of a mountain glacier. 1775
6. Lake below snowy mountain. 1291
7. Mayan ruins in the forest. 2382
8. Mosque and park. 2618
10. Sand dunes. 1698
11. City freeway (vertical). 2436
13. Overlook of an inhabited area. 2522
14. Coastal road with two headlands (promontories). 880
16. Single rock arch. 2102
17.   Bridge across river by oil tanks. 1293
18. City with three main streets (two cross) 2668.
23. House in the rocks with pool on shore. 1895
29. Desert scene with distant mountains. 2440
30. H shaped building. 863
31. Conical hill in desert. 2385
32. Serpentine river in mountains. 2229
34. Canyon surrounded by four buttes. 1594
35. Two pinnacles in desert. 2471
36. Two mountains behind a lake with trees. 1718
38. Row houses in a city. 2477
39. Mountain lake with curved rocky grassy shore. 2030
41. Tower and city. 1809
42. City with bridges over river forks. 2535
44. Stadium with skyscrapers and freeway. 2471
45. Large arch by the river. 1113
47. Road through woodland hills 2278
49. Large waterfall by a city. 2473
52. Aereal view of city, skyscrapers, cloverleaf. 2653
53. Reef with sandy shoreline. 2182
54. Rivers joining with a bridge. 1825
56. Canyon stream seen from a large flat rock. 1972
58. Horizontal canal through rolling farmland 2294
62. Loading facility. 2195
65. Star shaped fort on wooded shore. 1585
68. Snow capped distant peak seen from shoreline with trees. 1694
69. Rocky desert hills, dunes, peaks. 2474
70. Glacier flowing around a mountain with trees in foreground. 2302
71. Aerial view of lake surrounded by large mountains. 1964
75. Foreground rocky pinnacles with smooth slopes behind. 2268
76. Tall jagged snow capped mountain with smaller peak to left. 1540
77. Twin skyscrapers in a city by a river. 2088
79. Big flat rock with snowy mountains behind. 1985
81. River bend with flat highland (mesa) in background. 1685
83. Snow covered pyramid peak in rocky flatland 1446

84.   Cliff dwellings. 2436
86.   Urban peninsula in bay with prominant rock dome. 2496
87.   Plains with mountain peaks behind. 2301
96.   Reedy mountain lake with trees. 2470
97.   Two rock arches. 1644
100. Rocky shore with surf and palm trees. 2034
102. Ocean side recreational park with tower. 2515
106. Mountain lake created by a dam. 2378
107. Canals crossed by bridges and highway. 1995
109. A lake surrounded by sloped hills with sparse trees.
2319
110. View across a bay of a city at night. 1802
111. Shoreline houses on pilings. 2407
114. Ship at dock with bridge in background. 2159
115. Aereal view of rough coastline and coastal city. 2638
116. Open stadium surrounded by parked cars. 2544.
118. Two barren buttes. 2291
120. Skinny arch with rocks below. 2023
121. Large butte rising from field. 2197
122. Rugged coast with rocks. 1689
123. Large mountains with forked river below. 1558
125. Rocky sloping barren hills. 2239
127. Straited dome with trees below. 2441
129. Background cliff with grassy sand hills. 2072
130. Snowy stream with snowy peak behind. 589.
141. Towering rocks with a house on top. 2079
142. Crater with buildings on the edge. 2061
144. Curved river with trees and mountain range behind.
2197